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Automatical Cranial Suture Detection based on Thresholding Method

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Purpose The head of infants under 24 months old who has Craniosynostosis grows extraordinarily that makes head shape unusual. To diagnose the Craniosynostosis, surgeon has to inspect computed tomography(CT) images of the patient in person. It's very time consuming process. Moreover, without a surgeon, it's difficult to diagnose the Craniosynostosis. Therefore, we developed technique which detects Craniosynostosis automatically from the CT volume.

Materials and Methods At first, rotation correction is performed to the 3D CT volume for detection of the Craniosynostosis. Then, cranial area is extracted using the iterative thresholding method we proposed. Lastly, we diagnose Craniosynostosis by analyzing centroid relationships of clusters of cranial bone which was divided by cranial suture.

Results Using this automatical cranial detection technique, we can diagnose Craniosynostosis correctly. The proposed method resulted in 100% sensitivity and 90% specificity. The method perfectly diagnosed abnormal patients.

Conclusion By plugging-in the software on CT machine, it will be able to warn the possibility of Craniosynostosis. It is expected that early treatment of Craniosynostosis would be possible with our proposed algorithm.

Key Words Craniosynostosis · Thresholding Method · Cranial Suture · Automatic Diagnosis.

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Introduction

A normal child under 24 months of age has suture, an area where the cranial bone connects in the cranium (Fig. 1). Craniosynostosis occurs one in 2000 infants. It is provoked by early fusion of the cranial sutures [1] Suture divides into following categories depending on its type: sagittal, bicoronal, unicoronal, metopic, and lambdoid Craniosynostosis. This affects the pressure of the brain and skull growth. Therefore, early diagnosis is essential and infant must take the surgical correction [2,3].

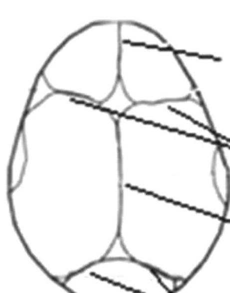

Fig. 1. Kinds of cranial sutures.

Currently, it is hard to diagnose Craniosynostosis other than by the surgeon directly looking at the 3D CT images. Some researches tried to determine the diagnosis by quantifying the malformation of the cranium for making automatic Craniosynostosis diagnose system. Another author proposes a method for evaluating the degree of using the anthropometric indices on cranial CT images [4-9]. However, merely using cranial shape data, the result was not satisfactory accurate. So, we focus on suture structure which is cause of Craniosynostosis. It is for high detection accuracy. In this study, we developed a technology in which we divide the areas in the CT volume, and automatically diagnose Craniosynostosis by utilizing each area's center of mass. Through several loose thresholding, we increase detection ratio of Craniosynostosis and decrease false detection of normal person. Also, using through simple calculation with positional information of center of mass, we can find abnormality or normality quickly.

Materials and Methods

Data set

To experiment of diagnose Craniosynostosis, we performed our experiment with 20 CT volumes of normal subjects under 24 months old and 20 CT volumes of subjects with Craniosynostosis (5 sagittal, 5 bicoronal, 5 unicoronal, and 5 lambdoid).

Rotation correction

If the direction of the cranium on the CT image is twisted, the accuracy of the automatic diagnosis decreases. Therefore, we correct the rotation of the CT image (Fig. 2). We correct the vertical plane that divides the cranium sagittal and horizontal plane that divides the axial.

The three points that determines the vertical plane are the anterior nasal spine, nasion and basion. We calculate the two vectors consisting three dots and calculate the normal vector $\vec{R}$ (Fig. 3). To set the surface normal vector to vector $\vec{i}$, we calculate the degrees between $\vec{i}$ and plane orthographic vector with z=0, and rotated the z-axis. Once the x-axis gets rotated accordingly to the amount of degrees between plane orthographic vector with x=0 and $\vec{i}$, the normal plane vector parallels with the unit vector $\vec{i}$.

For the horizontal plane, we use the left orbital and right porion. The plane does not get determined with two dots, but we determine the plane with the fact that it is vertical to the vertical plane. The normal vector of the vertical plane that we correctly rotated is the same as the unit vector $\vec{i}$. The normal vector of the horizontal plane $\vec{T}$ can be calculated by finding the inner product of the vector with two dots and $\vec{i}$. We then rotate the $\vec{T}$ (normal vector of the horizontal plane) so that it could be parallel with the unit vector $\vec{k}$. First, the x-axis rotation is performed by the amount of degrees between $\vec{T}$ orthographic vector with x=0 and $\vec{k}$. Then when the y-axis rotation is performed by the amount of degrees between plane $\vec{T}$ orthographic vector with y=0 and $\vec{k}$, the $\vec{T}$ becomes parallel to $\vec{k}$.

The cranium image rotation corrected by the two planes allows higher accuracy of diagnosis (Fig. 4) (10, 11).

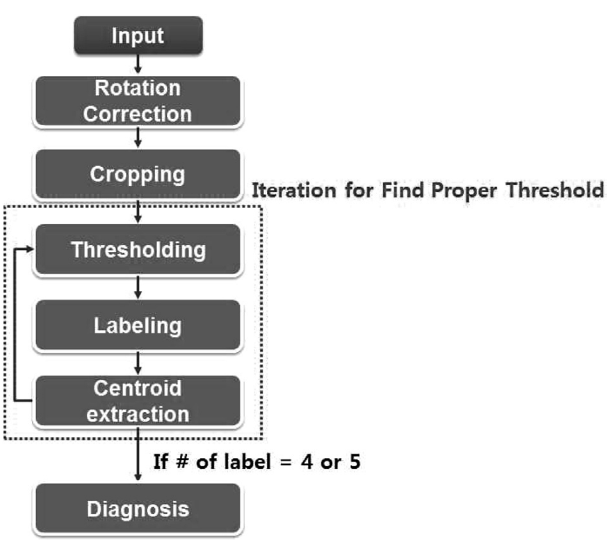

Fig. 2. Automatic Craniosynostosis detection algorithm.

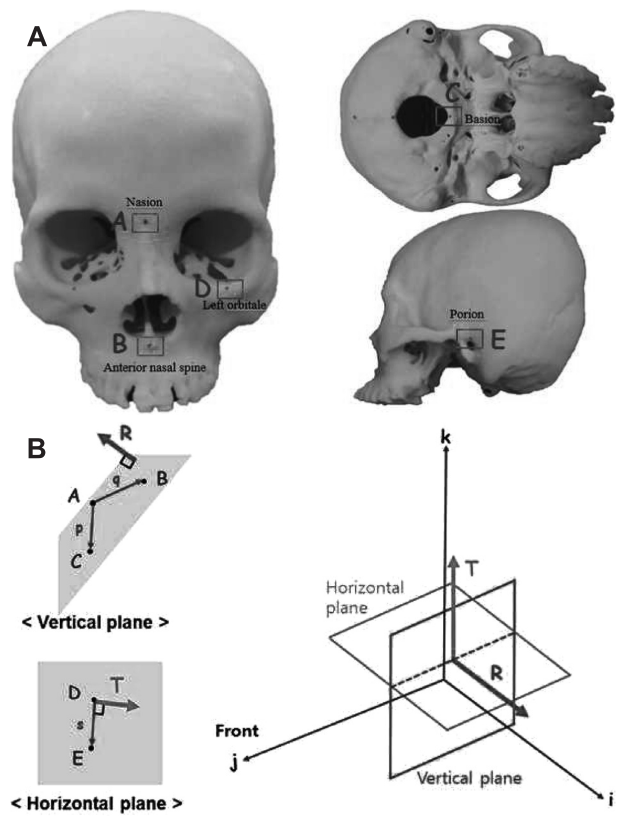

Fig. 3. A: 5Points for rotation correction. B: Rotation correction method.

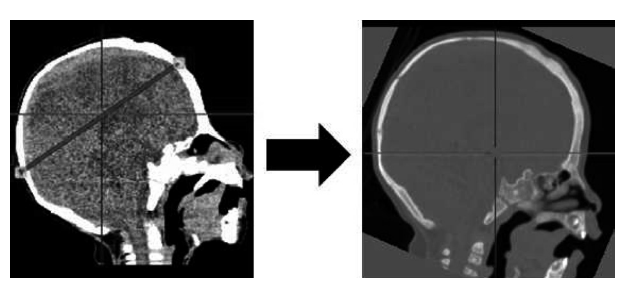

Fig. 4. Result of rotation correction.

Cropping

Our proposal method detects normality by analyzing characteristics of each cranial segment that separated by normal suture. We crop correctly rotated upper cranial part for extracting interested area. To extract the interest areas of the rotation corrected cranium, we cut the upper areas of the cranium where suture is. When cut in sagittal plane, we cut based on the z coordinate of center point of connect line between the prominent area of the frontal region(Prior pole) and the prominent area of the occipital region (Posterior pole) (Fig. 5).

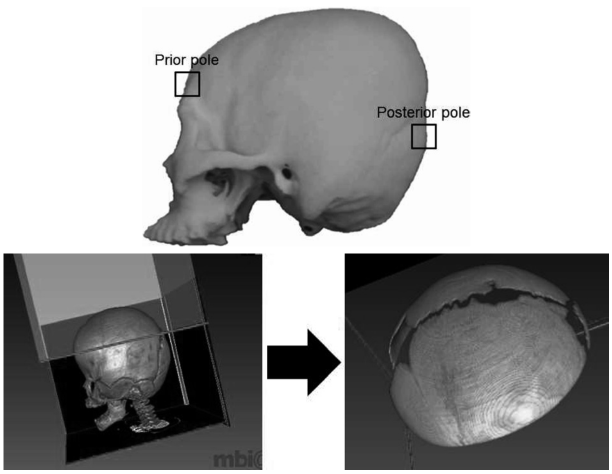

Fig. 5. Cropping of interested cranial area.

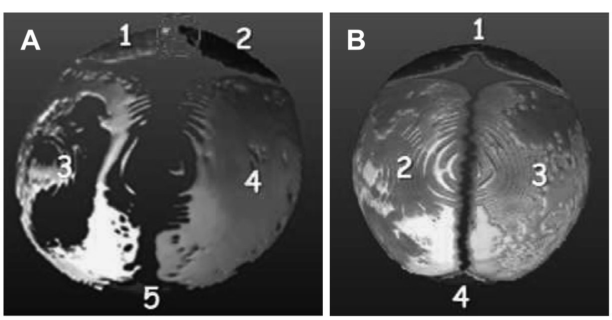

Fig. 6. Segmented cranial area.

Iterative Thresholding Method

Our proposal method is motivated from the fact that there is more than one threshold when cranium divides into 5 regions due to the suture. Although, even if the fetus is normal, the metopic suture of the frontal region could agglutinate early, and the areas could divide into 4 parts (Fig. 6). Our contribution is determine subject is whether normal or abnormal by finding threshold when cranium divides into 5 (or 4) regions through iterative approach. We then extract the cranium areas from the CT volume by using the Iterative thresholding method. When the threshold is increased by stages, the bone area slowly becomes visible, and the areas divide due to suture.

We label all the voxel close to one voxel into one class by using the Region Growing Algorithm. Region growing is a segmentation algorithm that is used widely in the image processing areas. The first point gets entered and extended to nearby pixel or voxel, and this continues until there is no similar neighbor (Fig. 7) (12-16). Points which divided by Thresholding consists cluster through label. During the Thresholding, bone part which has strong intensity on CT image is preserved and rest part is vanished. Therefore each cluster becomes points that consist of cranial area divided by suture.

Normal suture detection

The abnormality or normality is determined by analyzing 4

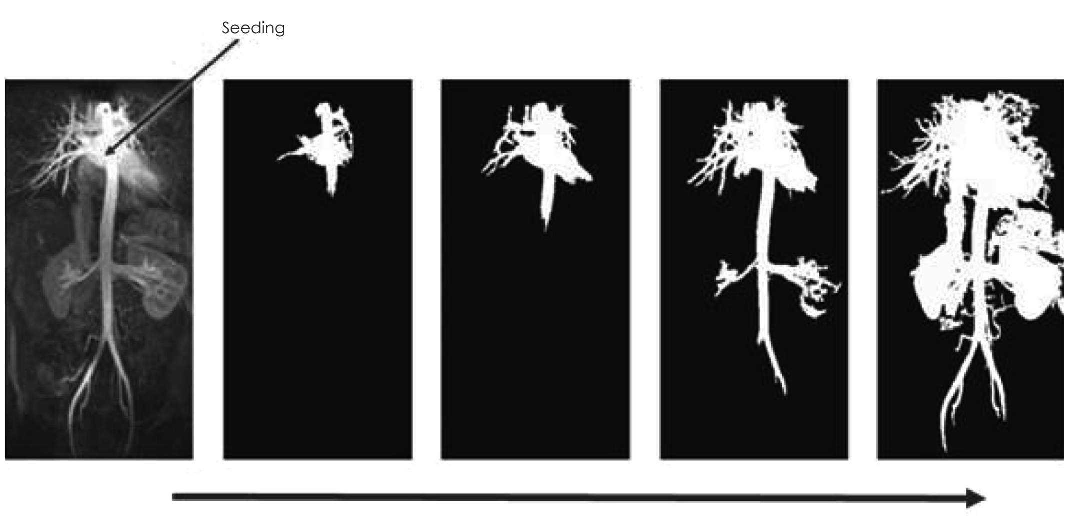

Fig. 7. Region growing.

or 5 numbered center of mass coordinate. First, we number each clusters by rounding from top to bottom based on their center of mass. In the case of having it divided into 4 by thresholding, the area divided by coronal suture is numbered as 1. The two areas divided by coronal, sagittal, and lambdoid suture is numbered as 2 and 3, and the area that is divided by metopic and coronal suture is numbered as 4 (Fig. 6A). If the cranium gets divided into 5 areas, for normal patient, the two areas divided by metopic and

Table 1. Diagnose algorithm pseudocode

```
if ( NumOfClass = 4 ) {

    // Condition 1
    if ( sign(x3-x1) = sign(x3-x4) and sign(x2-x1) = sign(x2-x4) and
        sign(x3-x4) != sign(x2-x1) ) {

        // Condition 2
        if ( | x1-x4 | < th1  and
            | ( (x3-x1)+(x3-x4) )-( (x2-x1)+(x2-x4) ) | < 2*th2 ) {
            Determine as a Normal
        }

    } else { Determine as a Abnormal }
}

if ( NumOfClass = 5 ) {

    // Condition 3
    if ( sign(x3-x1) = sign(x3-x2) = sign(x3-x5) and
        sign(x4-x1) = sign(x4-x2) = sign(x4-x5) and
        sign(x3-x5) != sign(x4-x1)) {

        // Condition 4
        if ( | y1-y2 | < th3 ) {

            // Condition 5
            if ( | dist(P1,P4)-dist(P2,P3) | < th4  and
                | dist(P1,P3)-dist(P2,P4) | < th5 ) {
                Determine as a Normal
            }
        }

    } else { Determine as a Abnormal }
}
```

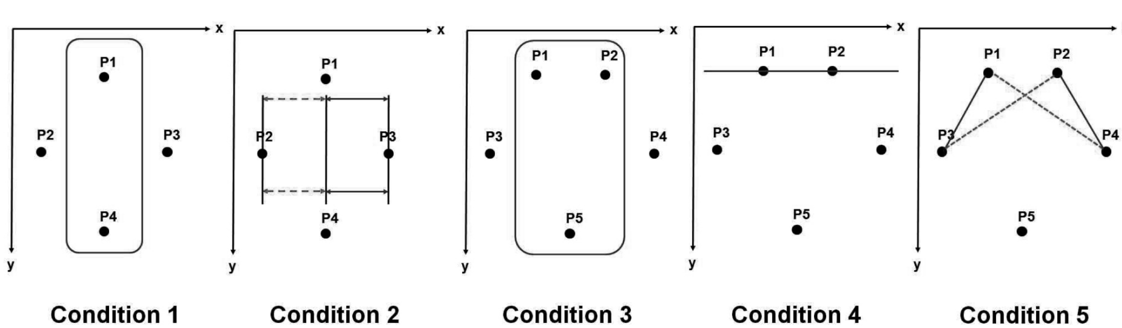

Fig. 8. Detecting conditions.

Table 2. Result

Cranial synostosis					
Test	Present	20	Absent	20	Total
Positive	True Positive (TP)	20	False Positive (FP)	2	22
Negative	False Negative (FN)	0	True Negative (TN)	18	18
	Sensitivity	100%	Specificity	90%	40

coronal suture are numbered as 1 and 2. The areas which got divided by coronal, sagittal, and lambdoid suture are numbered as 3 and 4, and the area that is divided by lambdoid is numbered as 5. (Fig. 6B) We determine whether or not the patient is normal by analyzing the relationship of the location of each area's center of mass, with the rotation corrected volume. We determine the subject as normal if the subject satisfies the following conditions, and determine the subject as abnormal if the subject did not satisfy at least one of the conditions. The determination conditions are as follows when the center of mass that is numbered is P_n, and the coordinates of each P_n is (x_n, y_n, z_n) (Fig. 8.).

The abnormality or normality was determined by using the numbered center of mass coordinate and the following 5 conditions.

Condition1 When there are 4 classes, the x-coordinate of P_1 and P_4 is located between P_2 and P_3.

Condition2 When there are 4 classes, the difference of x-coordinate between P_2 and P_1, P_4 are similar, the difference of the x-coordinate P_3 and P_1, P_4 are similar, and the difference between the above two are similar.

Condition3. When there are 5 classes, the x-coordinate among P_1, P_2, and P5 are located between P_3 and P_4.

Condition4. When there are 5 classes, the y-coordinate of P_1 and P_2 are similar.

Condition5. When there are 5 classes, the distance between P_1 and P_4 as well as P_2 and P_3 are similar, and the distance between P_1 and P_3 as well as P_2 and P_4 are similar.

Table 1 shows the way to determine whether fulfill the above conditions or not. The thresholds th_1, th_2, th_3, th_4 and th_5 determines whether the subject of the CT volume is normal or not in terms of the Craniosynostosis. If these thresholds are set strict, the possibility that the proposed method detects the abnormal subject increases. But the possibility that it decides the normal subject as abnormal also increases at the same time. Therefore, these thresholds should be set appropriate upon aims of the method.

Results

We separated the cranium areas of 40 3D CT volume sets by using the iterative thresholding method. We determined the abnormality and normality by looking at the relationship of each area's center of mass. As a result, through the proposed method, we were able to accurately and automatically diagnose Craniosynostosis on most patients. In the case of abnormal, we found the abnormality with 100% accuracy, and in the case of normal, we diagnosed 18 out of 20 to be normal. As depicted in Table 2, the sensitivity was 100%, and the specificity was 90%. This reveals that the proposed method is highly accurate in detecting a patient with Craniosynostosis.

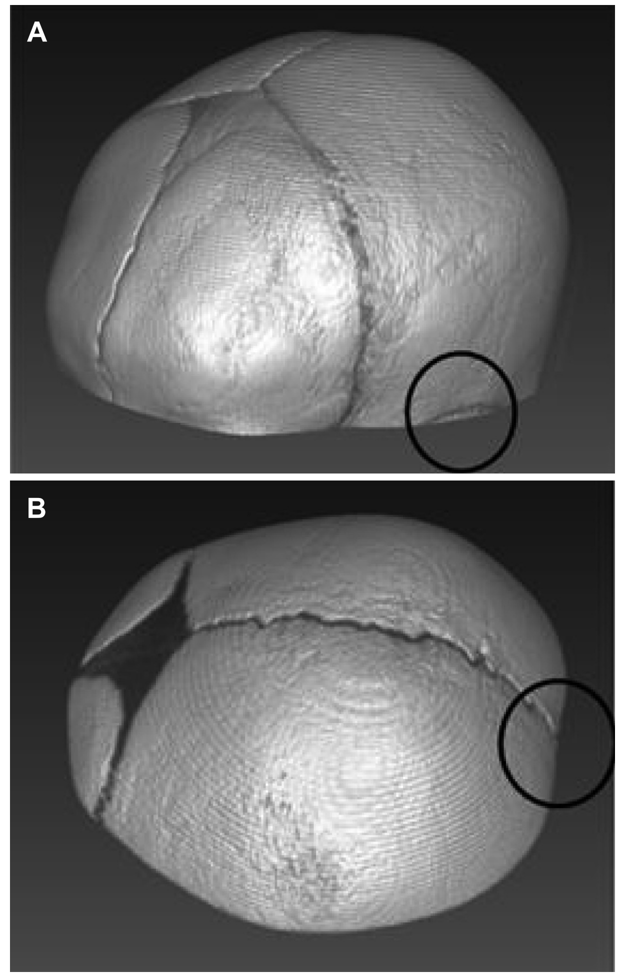

Fig. 9. A: Cropping takes too low on the cranium area. B: Cropping takes too high on the cranium area.

Discussion

The accuracy of the result decreases when the cropping takes too low on the cranium area due to the non-interested area is included (Fig. 9A). When the cropping takes too high on the area, the area divided by lambdoid suture does not get included, thus problem arises (Fig. 9B). In this study, the cropping took place based on the line that connects the most prominent area of the frontal region and the most prominent area of the occipital region when divided to sagittal plane. In most cases, we can get an accurate result when we crop it this way.

If the child's head is tilted back too much, the areas get included by lowering the crop z-axis. If the cropping criteria is higher, the areas by lambdoid disappears. This is reason why the prior rotation correction must be done (Fig. 10).

We adjusted the segmentation regions by increasing the threshold in stages when using the Iterative thresholding method. Small segmentation region should not be in consideration. So when constructing the point clusters, we ignore the cluster whose points are less then threshold t_n. In our experiments, we set t_n to 3,000.

In normal condition, the threshold that is divided into 4 or 5 areas exists depending on the existence of metopic suture. In the case of abnormal, however, the suture is not formed normally, so there may not be 4 or 5 areas.

For the 2 CT volumes we determined abnormal, small divided areas of cranium in the lambdoid suture exists (Fig. 11) In clinical point of view, this result is significant in that we can determine suspicious normal patient.

In this study, we used threshold method to measure the rela-

Fig. 10. Cropping without rotation correction.

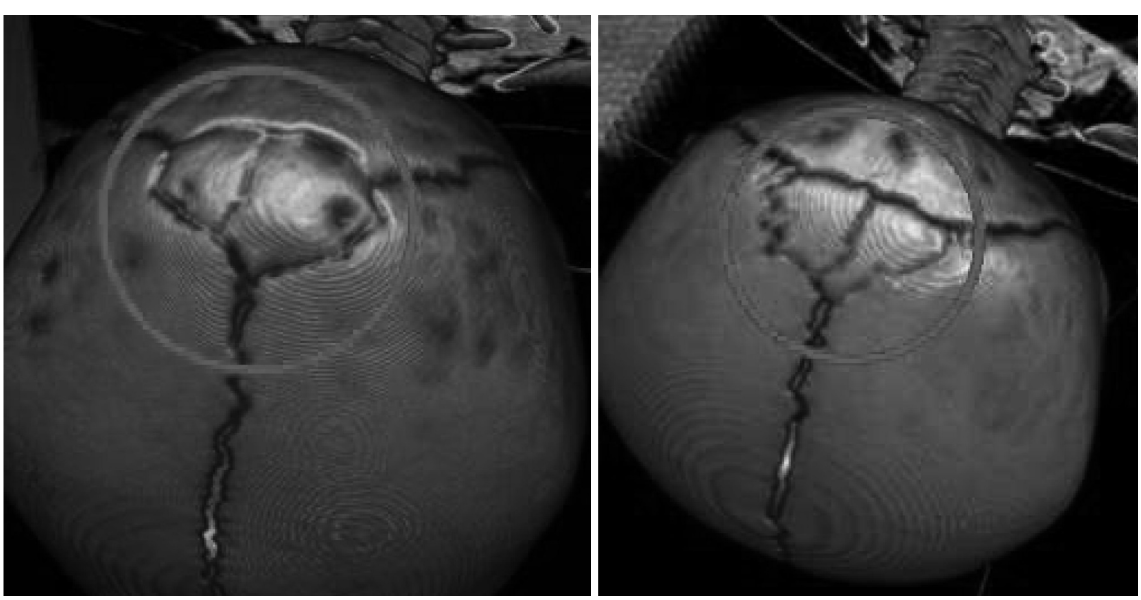

Fig. 11. Detected normal cases.

tionship among the clusters. Threshold method has its weakness in not being able to exceptional case. However, from the point of view of prevention of disease, it is more important to determine the abnormal patient as abnormal(true negative) then to determine normal patient as normal(true positive), and our method increases the sensitivity through several loose thresholding strategy. In our experiments, we set thresholds th_1, th_2, th_3, th_4 and th_5 to 18, 60, 8, 15 and 12 each.

Conclusion

We suggested an algorithm in which automatically diagnoses Craniosynostosis through the relationship between the center of mass of the areas divided by the suture. This method resulted in 100% sensitivity and 90% specificity. The method perfectly diagnosed abnormal patients. If a software that has the proposed method applied gets plugged in on the CT device, it could give a warning of the possibility of the Craniosynostosis. There are many cases currently in which not all of the CT images get analyzed and therefore not make an early detection on Craniosynostosis due to the lack of number in specialists. This system allows a promising future for the patients' early care.

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